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Technical Evaluation Report on Design to Cost and Life Cycle Cost

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

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AGARD Advisory Report No. 165

TECHNICAL EVALUATION REPORT

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on

DESIGN TO COST AND LIFE CYCLE COST

by

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ON THE
FLIGHT MECHANICS PANEL SYMPOSIUM
ON
DESIGN TO COST AND LIFE CYCLE COST

by

William E. Lamar
Consulting Engineer

I. INTRODUCTION

The AGARD Flight Mechanics Panel (FMP) symposium on "Design to Cost and Life Cycle Cost" was held in Amsterdam from May 19 to May 22, 1980. This meeting was organized because of the ever increasing importance of the Life Cycle Cost aspects of NATO systems. Its objective was to explore the state of the technology and share information on a wide range of Design to Cost and Life Cycle Cost topics.

The theme of the Symposium, evolved from FMP "Pilot Paper" No. 112 by Dr. I. C. Statler in April 1978, was stated in the Meeting Announcement, with more specific objectives.

"In all of the NATO countries, there is tremendous pressure for cost reduction and tendencies for other priorities to take available funding from military defence and preparedness. At the same time, the costs of developing, acquiring and operating modern weapon systems have been escalating. As a result, more and more military procurement contracts include specific provisions requiring the application of new design economics procedures to assure minimum total cost of ownership from development through the life of the system. These new concepts include design to cost (DTC), which is concerned with minimising the cost of acquisition of a weapon system and life cycle costing (LCC), which is concerned with the total cost of ownership of a system; that is, acquisition plus operation and support costs. The objective of this conference is to provide a forum in which those who are currently specifying, developing, and applying these new design philosophies can review and exchange information on how problems are defined, what techniques are being tried, and which ones seem to be working. The meeting will address the current concepts for resolving the conflicts between the traditional performance-oriented design team and the 'balanced' design team which incorporates reliability, maintainability and cost specialists within the design/engineering organization."

The purpose of this TER is to supplement AGARD Conference Proceedings No. 289 with a concise summary of the technical sessions and papers, to summarize overall findings and provide recommendations stemming from the meeting. The questions and issues discussed during the Round Table discussion are reported in some detail, since they are not included in CP-289.

II. SUMMARY & EVALUATION OF THE SYMPOSIUM

The symposium encompassed 26 papers presented in the following four sessions:

I. LCC Methodology and its Relation to Specifications and Requirements

II. Impact of LCC Analysis on Total System Design

III. Cost Control of Operations and Support

IV. LCC of Subsystems and Components

The 26 papers were presented by authors from four NATO countries as follows: France, 4; Germany, 4; UK, 7 and USA, 11. This was a good balance from the nations having the most extensive aircraft development and production.

The Round Table session of approximately 1½ hours duration, which followed Session IV, addressed a number of the important aspects of LCC. It utilized a panel consisting of a chairman and five additional participants from the four countries noted above, and included extensive participation from the symposium participants. The time allowed for the Round Table session did not permit direct discussion of all questions posed at its beginning. An additional time allowance would have been productive in view of the very active participation and useful points of view being presented.

1. <u>Summary of Session I - Life Cycle Methodology and its Relation to Specifications and Requirements.</u>

This session, chaired by Dr. I. C. Statler, USA and Ing. Gen. J. Forestier of France, included seven papers which provided perspectives from the UK, USA and Germany regarding the evolution of life cycle cost methodologies, their definitions, applications, advantages, disadvantages, basic problems and progress made. The large numbers of examples illustrated LCC methodology applications and their utilization in decision making, trade studies, program cost control, contractual incentives and cost reduction. The importance of adequate LCC data for credible cost estimates was emphasized and several data acquisition systems were summarized. LCC analyses and prediction methods, of key importance to the

applications of the LCC concepts, were addressed in several papers. LCC trades provide an important basis for decisions to transition advanced technologies to systems, but technology changes reduce the value of the existing data base in predicting future costs. This problem is addressed in several papers. The importance of improving cost predictions and reducing cost in the O&S area was stressed by a number of the papers. It is generally agreed that this area requires considerably more management attention. The papers reflect a general agreement that basic LCC approaches and methods are well understood and being utilized extensively. The major impact of military requirements in determining system LCC was discussed in a number of papers, and the framework of processes for improving the cost effectiveness/LCC tradeoffs and considerations was reviewed in several. However, no single paper was devoted to this critical area and the subject was not reviewed in depth. It is now well accepted that the major portion of total LCC is predetermined during the early design phase of the program. The importance of LCC analyses and tradeoffs during this phase, while decision flexibility still exists, was shared by all papers.

R. Chisholm of British Aerospace, UK (Paper No. 1) pointed out the ever increasing importance of life cycle cost analyses (LCCA) as a tool for strategic decisions, detailed tradeoff studies, design optimizations, the establishment of management policies, sales, and the establishment of contractual incentives. Timeliness in doing the cost trades early in the program is of key importance since some 80% of the LCC is committed by the time 20% of the program cycle and some 8% of the funds are expended. A detailed example of the value of investing additional funds during the design phase showed a sizeable pay-off for an advanced tactical aircraft. LCC data is expensive, and only the quality needed should be obtained. An overly formal LCC system is not needed if necessary cost/technical tradeoffs are already being made. The key to success is the ability to provide timely and credible analyses and using them in conjunction with mature judgments.

R. E. Houts, U.S. Naval Air System Command (Paper No. 2) summarized improvements in O&S cost estimating capability achieved over the past five years. Previous systems were inadequate to analyze the O&S implications of design because of the lack of data at the lower level element of cost. A new system will provide major improvements by providing maintenance cost visibility to the black box level and traceability of the subsystem level cost of a particular type.model/series aircraft. Cost estimating approaches are discussed, with summaries of the pros and cons of each and an example of use of the scaling technique for estimating O&S for a new radar system is shown in detail. A number of problems still exist in acquiring credible data, however a highly knowledgable analyst can compensate for many of the problems.

R. B. Lewis, III, et al of the U.S. Army (Paper No. 3) discussed the evolution and application of design to cost (DTC) and life cycle cost (LCC) techniques to helicopters and turbine engines, with emphasis on lessons learned. Applications of DTC techniques for cost program management, trade studies, and contractual requirements, including several types of incentives, are reviewed with examples from several Army programs. Experience shows DTC goals are discouraging demands for additional performance that increase cost, and even have become more important than technical requirements during design and development. DTC has been effective in controlling production cost, but much more needs to be done in the O&S arena.

W. E. Lamar, Engineering Consultant, U.S.A. (Paper No. 4) provided an extensive review and assessment of the evolution of cost reduction activities for military aircraft systems over the past decade. The review addresses the complexity of the overall LCC problem, basic problems, issues, progress made in focusing attention to the cost problems, institutionalizing LCC, developing data bases and prediction methods, and in applying new technologies to reduce cost. The use of the system engineering techniques and a systems preliminary design/mission analysis process provides a powerful tool for the exploration and tradeoff of system alternatives, and the determination of cost-effective military requirements. Technical demonstrators offer a means of reducing the current extensive time for system development from a concept to operational use. Experience shows that advanced technology can be very effective in reducing system cost, and such use should receive continual emphasis.

F. D. Carlson, Boeing Aerospace (Paper No. 5) discussed the problems of predicting and reducing cost in the operations and support (O&S) area, and emphasized the need of a relatively new activity termed "Design to Life Cycle Cost Research". The objective is to research the O&S process and logistics systems, identify cost drivers, evaluate tradeoffs and develop innovative solutions to reduce O&S cost. Lack of prior emphasis has not only increased O&S cost but reduced operational availability. Research to date has shown that a relatively small number of high cost drivers impact a high percentage, 70 - 85, of O&S cost in many areas. High cost drivers identified include: the number of unique systems, manpower, facility locations, concepts of inspection and test, and material distribution. A key need is to find a way of using people and material in a timely and more economical manner. Little match-up is shown between design/maintenance concepts used in the development process and the ownership deficiencies covered by the O&S research. Expenditures to improve system maintenance features may not be realized in the field because of this.

H. Greiser, Donnier Germany (Paper No. 6) reviewed the importance of cost analyses to system design, with emphasis on cost as an active element of design, and cost analysis as the "Continuous interface between the desirable and the feasible". Cost analysis is viewed as an essential tool of systems engineering in determining the impact on cost of technical and operational requirements, specific program requirements, and budget constraints in the identification of cost drivers and for the evaluation of design

alternatives and cost effectiveness tradeoffs.

J. M. Jones, British Aerospace, UK (Paper No. 7) discussed the evolution of techniques for LCC analyses, and the importance of controlling aircraft O&S costs by a coordinated approach to LCC analyses during the conceptual design stage. The LCC model should continue to be evolved and applied throughout the program. Lack of LCC estimating credibility is still a major problem in applying results. Estimates vary between contractors and there is considerable misunderstanding as to how they should be used. These problems were vividly portrayed by a number of charts. Distinct differences exist between the need for accurate cost data in predicting future budget levels and that needed for conducting comparative tradeoff studies. A strong committment to LCCA will provide payoffs, and is critical to the achievement of long term credible results.

2. Summary of Session II - Impact of LCC.Analyses on Total System Design

This session, chaired by Prof. R. S. Shevell, U.S.A. and Mr. H. Franke, Germany consisted of seven papers addressing various aspects of LCC analyses. Three papers, one on the Hornet, one on the F-16 and one on the AS-350 helicopter examined the application of design to cost techniques, and impact of LCC analyses on the system design. Two papers examined the DTC of structures. One utilized components of the Tornado aircraft to show the significant cost and weight reductions possible by integrated structural design, and the other examined the general payoff of new technologies with emphasis on major improvements through application of advanced composite structures. The other two papers examined methodologies and cost analyses. One, related to the paper on the AS-350, was devoted primarily to the development of an organization approach and methodology for a design to cost program, and the other to an improved method of estimating direct operating costs for airlines.

R. D. Dighton of McDonnell Aircraft (Paper No. 8) described and provided many examples of the design and management techniques used to develop the F-18 Hornet to an affordable LCC. Cost was a factor of major importance throughout this program. Numerous cost LCC incentives are included in the contract, and much attention is given to improve reliability and maintainability (R&M) by a 3 to 1 factor. The prime means is by improving the R&M of the basic system design. Reliability incentives are included in both the system and subcontracts. Improvement in operational reliability is expected from the accelerated test of major subsystems in a facility which simulates a realistic "operational mission environment" (OME). It is concluded that DTLCC is little different than designing to other technical parameters. Of key importance are realistic requirements, serious trade studies, rigorous design reviews, and multi-disciplined design teams and incentives.

M. Rowell of General Dynamics (Paper No. 9) reviewed key LCC aspects of the F-16 fighter aircraft, which is based on selected application of innovative new technologies, use of available low cost materials and equipments, numerous configuration tradeoffs and the use of cost minimization principles throughout the prototype program, and DTC/LCC concepts throughout the full-scale development and production programs. The two prototypes permitted the exploitation of advanced technologies and reduced risks and potential cost increases in the FSD program. The prototypes were procured on a cost incentive contract, with a concise performance type specification the only requirement. The framework of FSD program, acquisition, and O&S cost control activities, and examples of contractual provisions for reliability improvement warranties and award fees for logistics support achievements are reviewed. This program was unique in being one of the first to include innovative applications of DTC/LCC, with RIWs, award fees, other incentive provisions in the contract.

T. E. Seibert of MBB (Paper No. 10) utilized structural components of the Tornado MRCA to show how cost of the prototype structure could be significantly reduced by structural integration during design for the follow-on production. Results of cost reductions achieved for 2 flat panels, the wing carry through box, and the taileron showed component cost savings ranging from 15% to 33%, plus weight savings ranging from 4% for the flat plates to 18% for the taileron. The key was a simple design rule to keep the number of parts and fasteners at a minimum.

F. Cordie of Marcel Dassault-Brequet (Paper No. 11) reviewed design to cost concepts in the application of new technologies, with emphasis on the evolution and application of advanced composite structures. Aircraft contractors, through their integration responsibility, must lead an effective cost reduction effort for the entire system, and develop basic concepts for application of DTC, including innovative technology solutions to cost. Cost predictions are of key importance to the tradeoffs, but suffer inaccuracy when new technology is involved. Advanced technology components, such as composite structures, must be evaluated, in terms of the total system LCC, not just that of the component. It is concluded that advanced composite technology offers significant savings, e.g. 11% gross weight, 6% in cost and 4% in fuel for an advanced combat aircraft.

R. Tassinari, SNIA (Paper No. 13) summarized the basic principles, organization, functions, and activities of specialized teams established to implement DTC/LCC and assure total cost control, initially for the A 200 Airbus and now for the A 310. Much credit is given to training of personnel in value analysis and DTC methods, and the establishment of interdisciplinary teams for the specific tasks. Results are very beneficial in achieving cost objectives.

K. Grayson, American Airlines (Paper No. 14) discussed, with many charts, the evolution of methods for estimating commercial aircraft direct operating costs (DOC). A new

method has been developed because of the older method deficiencies in estimating costs for turbine powered aircraft. The new method improves understanding and provides the means of estimating and analyzing maintenance cost factors for comparative purposes. Specific cost drivers are identified for both detailed costing and review. Analysis of the data base and cost drivers provides excellent insight into the basic factors affecting airline operating cost and provides the basis for corrective action where possible. The high cost of fuel, now over 50% of a DC-10 DOC, justified acquisition of fuel efficient aircraft.

R. Mouille, (SNIAS) (Paper No. 15) reviewed the application of DTC to the Ecureuil AS 350 helicopter which was developed for commercial needs, with the direct objective of reduced costs. Previous studies of Allouette SA 318 helicopters showed maximum savings of about 5% unless major changes were made to tooling. By application of DTC concepts reviewed by Tassinair (13) and extensive innovative design by a small highly competent team, a new low cost helicopter was evolved, with manpower cost expected to be only 12.6% of production cost compared to 47% for the SA 318. Substantial component piece part numbers and weight reductions were also achieved, e.g. main rotor hub parts were reduced 82% and weight 45% compared to the SA 318. These results were achieved through major simplification to design and extensive reduction in the number of parts. Decisions made in the early design phase were critical to the results.

3. Summary of Session III - Cost Control of Operations and Support

This session was chaired by Drs. J. Buhrman, Netherlands and Mr. B. Curis, France, and included five papers to examine aspects of cost in the operations and support area. Three papers provided interesting concepts and perspectives regarding reliability and maintainability. The other two papers examined approaches and methodologies for total LCC design, and although including the O&S area from a methodology viewpoint, addressed the total problem rather than O&S.

F. S. Nowlan, United Airlines (Paper No. 16) reviews the concept, principles, methods and payoffs of a high cost/safety effective aircraft maintenance process termed "Reliability Centered Maintenance" (RCM). The concept has evolved into a well defined and highly structured process. The objective of this program is the efficient use of the maintenance process to protect and restore, when deterioration occurs, the inherent reliability of the system design. This permits realization of the full safety and economic operation capability of the design. A decision diagram technique and ordered set of priorities is used to estimate the consequences of function failures on safety and economic cost/effectiveness, and then to determine what scheduled maintenance can accomplish. A decision logic provides for default answers to protect safety. Considerable cost savings have already been utilized by application of this process. It is well thought out and should be useful for other operations and types of complex systems.

G. W. Bleasdale, BAE (Paper No. 17) critically reviews and provides many objectives and perspectives regarding cause and effect for a wide range of engineering aspects of life cycle costing. LCC is noted as a "method of forecasting the cost of future events", and likened to the problems of weather forecasting. Emphasis is given to the cost of support and its related areas of maintainability, reliability improvement warranties and other incentives, repair cost, and numerous specific examples of unforeseen support concepts. The paper is replete with perspectives that provide useful lesson learned guidelines.

E. Huie, et al of Northrup (Paper No. 18) reviewed the use and importance of LCC analyses in the attainment of a balanced performance, schedule, and minimum cost solution to the design and development of weapons systems. LCC analyses are shown as essential in quantifying the numerous factors and parameters necessary to achieve a balanced solution, and in providing a figure of merit for selecting the best alternative. LCC analyses provide valuable inputs for a large number of other needs, e.g., source selections and resource planning. The key cost driver in LCC is the set of performance, mission capability and O&S requirements and other specifications which the design must meet. O&S cost drivers, which are strongly affected by the design, include unit spare cost, fuel, MTBF, meantime to repair (MTTR), personnel skills and numbers, maintenance concepts and utilization rates.

K. Wickel, IABG, Germany (Paper No. 19) provides a number of basic thoughts regarding the meaning, scope, understanding of DTC and system LCC concepts and their applications. Concern is expressed that the widely used DTC phrase can lead to oversimplification of the underlying problems and objectives, and thereby result in serious deficiencies in military capability. It is suggested that the DTC functions be separated from the tasks of the military planners, e.g. define to cost and organize to cost, and subdivided into three aspects. (1) design to financial feasibility, (2) design to personnel feasibility and (3) design to systems LCC. Typical over-emphasis on the first aspect can have a number of negative effects. More emphasis on the 2nd aspect is necessary to improve capabilities and reduce cost in the O&S area. In the 3rd aspect, LCC provides a criterion of major importance for design tradeoffs, system option assessments, and force mix analyses and decisions. Suggestions are provided for solutions to a number of the problems inherent in over emphasizing the first aspect.

G. R. Thornber of BAE (Paper No. 20) discussed maintainability and its various functions. Different intepretations of the parameters involved were shown by a number of examples to significantly affect the way maintenance costs are accumulated, and complicate the problem of obtaining credible information for life cycle costing. Insight is

provided into the structure of the maintainability activity and the manner in which various tasks and costs are categorized. The process of establishing maintainability targets is noted, and issues associated with demonstrations of their attainment are shown to be far from straightforward.

4. Summary of Session IV - Life Cycle Cost of Subsystems and Components

This session, chaired by Prof. G. Schanzer, Germany and Prof. M. Geradin, Belgium, contained seven papers addressing various aspects of cost, with one on total aircraft systems, one on avionics systems, two on mechanical/hydraulic systems, and two on engines. Two of these, the one on avionics and one of the propulsion papers summarized recent AGARD Lecture Series on LCC in their respective areas. The reader will find many interesting points in these papers and acquire a good appreciation for the similarity between the approaches and methods for LCC reduction in the subsystem area and those in the total aircraft systems area. This shows that there has been much interchange of objectives and methods between the two and that much can be learned by sharing the experiences. A chart (23) showing the relationship between LCC and Operational Availability warrants attention.

J. Bollman and H. Lankenau of VFW (Paper No. 21) addressed the importance and a systematic method for estimating the relative total cost of alternative aircraft systems to provide a criterion with sufficient credibility for decisive system decisions, and also a basis for warranties in equipment contracts. Their method, the framework of which was shown in some detail, requires increased depth of system definition and cost analysis during the preliminary design phase. It is concluded that a genuine DTC program requires the early availability of credible technical and cost information so that agreement can be obtained between all parties as to the total cost and quantified values in the specifications. O&S cost experience in the field requires continued statistical monitory in order to identify variances from the target cost and implement necessary fixes.

M. Eslinger, MHB, (Paper No. 22) reviewed the use of cost reduction concepts in the development and production of landing gears, hydraulic wheels, and brakes. Cost reduction activity was based on four concepts: Industrialization, Value Analysis, DTC and DTLCC. After analyses and simplification of drawings and specifications during Industrialization, DTC cost targets are established by Value Analysis and engineering in close relationship with customers because of cost/specification interactions. The Industrialization and Value Analysis/Engineering Activity is assessed by a payoff factor consisting of the ratio of the cost savings over a two year period divided by the cost of the studies. Payoff factors of 14 and 22 respectively are typical, and significant production cost and life cycle cost reductions were shown for a number of aircraft components. DTLCC of aircraft brakes resulted in cost per landing reductions of 70% and production cost reduction of 45%. The key to these results is the process, competent and trained personnel working in teams, rapid and reliable calculation methods, and continuous cost control.

I. J. Gabelman, Tech. Assoc. U.S.A. (Paper No. 23) concisely summarized key aspects of each of the four 3 hour lectures of AGARD LS-100 "Methodology for Control of LCC for Avionics Systems" conducted in May '79. Dodson's lecture described parametric cost estimating methods, including a method of measuring and incorporating the effects of technology changes in LCC analyses. Kiang described a unique LCC methodology which related LCC and Operational Availability parameters in quantitative terms and provided for tradeoffs between these important objectives. Klion included discussions of models which provide a means of measuring the cost of reliability improvement efforts in relation to the reliability improvement in the developed equipment and its value in reducing maintenance costs. Reich pointed out the difficulty of acquiring credible reliability maintenance (R&M) cost. R&M difference between systems are even more difficult. Varying R&M definitions currently in use complicate the problem.

R. G. Rose, Marconi Avionics, UK (Paper No. 24) makes a plea for "Design to Total Cost", and examines the DTC activity in relation to achievement of system availability. High operational readiness is dependent upon systematic evaluation of the design and support characteristics of the system during the system engineering process. This involves assessment of the design impact on the O&S requirements. Unfortunately, frequent neglect of ownership cost also tends to neglect many of the parameters which exert a major impact on operational availability. The solution is increased early consideration of reliability and maintainability, and design to total cost.

E. J. Jones, MOD, UK (Paper No. 25) summarized the proceedings of AGARD LS-107 "The Application of DTC and LCC to Aircraft Engines" - given during May '80. Each of the nine lectures is described but much more emphasis is given to the one by Nelson which described a methodology for LCC analyses of turbine engines. Relevant points from this paper include the following: Decisions about engine performance/schedule/cost must be made at the system level rather than with the engine alone. Engine ownership cost are significantly larger and different from those found in past studies. Component improvement programs cost as much during the life of the engine as the initial cost to develop the engine thru the model qualification test. Performance/schedule/cost models compare reasonably well with development and production experience, but results are mixed for O&S costs. Review of some 2000 detailed drawings of several production engines by interdisciplinary engineering terms uncovered many examples of unnecessary costs. Adoption of the "On-Condition Maintenance Concept" (OCM) provides the potential for reducing engineering O&S cost by fully utilizing engine part life and reducing maintenance frequencies, but requires more sophisticated O&S forecasting methods. Jones noted that savings up to 30% can be achieved during the design phase by use of multi-disciplined management techniques.

R. Panella, et al, AFWAL, U.S.A. (Paper No. 26) reviewed the impact of advanced technology on turbine engine LCC, and the development of models capable of assessing LCC payoffs of the new technology. Emphasis was given to a new "Reduced Cost Turbine Engine Concept" program which is aimed at assessing cost reducing advanced technology concepts in terms of both engine and system LCC. The program includes development of a LCC model which is capable of identifying the cost effects of new turbine engine technology at the component level. LCC analysis of the payoff of a number of new technologies indicates savings in both engine and weapon systems LCC. The system LCC savings is greater when the new technology improves engine performance or weight, rather than just reliability, maintainability or manufacturing costs. A transpiration cooled combuster showed reduction in engine LCC of 99 million dollars, but savings of 353 million dollars, or 2% of LCC for the system. It is concluded that assessments of the LCC impact of advanced engine technology should consider the total weapon system LCC, and several other factors, such as fuel cost and usage, and engine components maintenance.

A. J. Eccleston, Lucas Aerospace, UK (Paper No. 27) examined costs of engine hydro-mechanical fuel control systems, and the process utilized to obtain minimum cost. These small, highly complex, close tolerance mechanisms, which have to operate in a hostile environment, and which are made in a variety of types in small quantities by a batch process present an interesting challenge to cost reduction techniques. The approach and methodology to cost reduction reviewed in the paper indicate a very logical process, similar in many respects to that used for major systems. Since the basic cost driver of these fuel control systems is machining, assembly and testing manpower, extensive analysis by both function and parts is used to identify specific manhour cost drivers and solutions to reduce cost. Care is taken to identify parts common with other components, because any improvements will also benefit other components, provided the interface requirements are maintained. Otherwise a lack of standardization could occur. Results show that the process and value engineering activity reduces cost by some 20% for new parts and 8 - 10% for existing parts.

5. Round Table Discussion

The purpose of this session was to provide an opportunity for discussion, by all participants of the basic issues and questions related to the overall objective of the meeting. It was organized in a panel discussion mode, with initial discussion by panel members as a catalyst for further discussion on the topic by all symposium participants. The panel consisted of a panel chairman, and five additional members as follows:

Chairman: R. J. Balmer, BAe, Kingston, FMP Deputy Chairman

Members: F. T. Carlson, Boeing Aerospace, U.S.A - Author

R. Chisholm, BAe, Warton, UK - Author

P. Hamel, DFVLR, Germany & FMP Member

W. E. Lamar, Consulting Engineer, U.S.A. Former FMP Member & Author

R. Tassinari, SNIA, France - Author

The plan for the session involved opening comments by the Chairman, first to explain the plan for the session, next a review of the four questions to be posed by the Chairman during the session, and then broad comments on LCC as an introduction to the discussion. This was to be followed by initial 3 - 5 minute comments on the first question by two panel members, and then, discussion was to be opened to all symposium participants. After a discussion of the first question, the Chairman was to pose the next, and so forth. Actually, the extensive participant discussion resulted in nearly all the time being spent on the first question. Discussion would have continued much longer had not the Chairman elected to stop it, and turn to question 4 to permit a brief discussion before time limits required adjournment. Although not addressed directly by the Panel, various aspects of the other two questions entered into the discussion of Question No. 1. During the session there were some 44 separate discussions in addition to 3 by the chair in opening and 10 additional in comments. Of the 31 remaining, 29 were on the first questions, with 20 from the floor.

This session is summarized, and in part paraphrased, in some detail to permit the reader to acquire a realistic understanding and perspective of the actual discussion. With much regret, the names of the many contributors to the discussion were deleted because of the impracticability of coordinating with them the writers interpretations of their comments.

Four questions to be posed by the Chairman: (if time limits permit)

1. Do governments care enough about DTC and LCC to do something?
2. Can government be sure that industry has given adequate consideration to DTC & DTLCC?
3. How can we get the incentive into industry to do what is needed?
4. Can the military learn any lessons from the civil side?

Mr. Balmer next proceeded in his opening discussion on LCC, and upon completion called upon Mr. Chisholm and Mr. Lamar in turn to discuss Question No. 1. The meeting was then open

for comments by all participants. Summaries of the initial statements by the Chairman and the two panel members, and the comments from participants follow:

Mr. Balmer:

This will address the broad aspects of design to cost (DTC) and Life Cycle Cost (LCC), from a background in military aircraft design. The current very strong interest in DTC and LCC, and the reason for this symposium, results from the rapidly increasing cost of buying and owning military aircraft. DTC and LCC are two rather different things. DTC addresses the cost of buying the system, including manufacturing costs which we must not forget. It involves the money in the budget for the immediate future, and affects the size of the force. It is managed by a project officer who will probably be replaced in time. Life Cycle Cost is concerned with the future. For systems currently in service, there is little the manufacturer can do to make them cheaper to own, but the user may be able to change procedures and his organization to reduce costs. For a new system, the manufacturer can improve its life cycle cost, but he needs incentives, and that generally requires more money now. The customer, although concerned about LCC does not appear very willing to invest in reducing costs in the future. He would rather buy more new systems now, and hope they will be cheaper to operate and support in the future. He may be right. LCC could be fallacious, as some have said. The blame for the current cost problems, both in acquisition and ownership must be shared by the customer. He still wants better performance and more sophisticated equipment. This is specified in some detail, likely more than needed. But the customer also wants the system to be cheap and easy to maintain. Although he may really want the technical aspects which are specified in so much detail, wouldn't it be better to simply require the design of the cheapest aircraft that will accomplish the given mission, and leave it up to the designer to do the job properly? Further, the customer could possibly reduce LCC by examining whether or not maintaining his manpower at established levels makes the new aircraft more operationally available.

To amplify the first question, should not governments simplify and reduce requirement specifications to say what is needed, but not design the aircraft? Could they not simplify and reduce the mounds of documentation that now absorb many manhours, and reduce the necessity of compliance with military specifications or equivalents? The real need is for a product that will be effective in operational use rather than meeting a number of arbitrary specifications.

Mr. Chisholm:

There is no doubt that the UK cares very considerably about costs. At every phase of a project, they are complaining about the cost. Regardless of the phase or time, our costs are too high. We obviously have to accept this. Further, we are forced by the competition in the market place to address these particular problems. But the question is, do we really address cost of the different phases at the right time. Some analogies may help. Look at the project of the mousetrap that is a superbly engineered, fully certified mousetrap that is very expensive to buy, and may also be expensive in use, but is extremely effective. One could become involved in a very detailed, expensive analysis of this particular piece of equipment to prove that it is too expensive, and then spend a great deal of money and attention making it a little cheaper. In the meantime no one has been addressing the real problem of another project, where great elephants are being developed willy-nilly. By the time their costs are known, it is enormous and trampling our profits. Our only way of addressing that problem is to consume the elephants one bite at a time. Now what should have been done in both cases, was to think about the best way of meeting the particular requirements. That means approaching the problem with the right sort of tradeoffs during the feasibility stage at the beginning of the project. Governments may not be capable of thinking 10 years ahead, because they don't last that long. Hopefully, industry will last that long. We recognize that the UK MOD feels strongly that we should be looking ahead, but I'm not sure we're getting quite the encouragement we deserve.

Mr. Lamar:

There should be little question that government cares. If government didn't care, we wouldn't be here today. Government has done a tremendous job of focusing attention on the cost problem. Government has expressed its concern, and they've aroused the interest of many people and organizations, including AGARD, and hence we have this meeting. So obviously government cares, but government's a big organization with a lot of different people who come and go, so a real question is: Do the people who are managing the program when the program is going, care? The answer here is also yes. The problem is they may not know exactly how to go about it. In order to improve that situation, and to maintain direction as people come and go, much work has been accomplished to institutionalize the process in the U.S., and from what we have heard, also in Germany and the UK. For some 10 years in the U.S., we have had DOD Directives 5000.1 and 5000.28 that govern systems acquisition and Design to Cost. These regulations include many specifics for design to cost during the acquisition phase, and some goals for design to life cycle cost. One problem is the lack of adequate operations and support (O&S) data, and the confidence necessary for full design to life cycle costs. The requirement to establish some LCC goals requires serious attention during design to life cycle costs. For example, a SPO director must submit a plan which addresses a number of LCC factors, e.g. mean time between failure (MTBF) and Reliability Improvement Warranties (RIWs) for various subsystems. A continual problem is the lack of credibility in many of the studies that are submitted regarding life cycle cost. I would like to challenge the participants here, that if you

were running the government, or if you were a Systems Program Office (SPO) director, how would you go about it? Do you think we have enough data now to make those kinds of high cost decisions, because it does mean spending dollars today out of a rather tight budget in the hope of a future savings. If cost reduction is the only gain, at a 10% discount rate, you would have to realize a $1.00 savings 10 years from now to justify spending 39 cents today. You also have to consider the fact that funds are very limited, and the nation must fight the crucial initial phase of the next war with the systems actually on hand. Therefore, there is much pressure on spending the money to buy adequate numbers of new aircraft. There are many, many factors here. Most everyone wants reduced O&S costs in the future. They recognize that the O&S problem, which absorbs some 60% of the service budget, is reducing the capability of buying the new aircraft needed to upgrade the current force. But they're in a box. They face a lack of credibility in the LCC estimates. Potential O&S savings require the sure expenditure of dollars today. This detracts from the performance capability or number of aircraft under development. To what extent should funds be diverted for a potential future payoff that involves a number of uncertainties? Despite these concerns, as discussed at our meeting here, a number of actions have been taken to reduce O&S costs. What else should and can be done?

Participant Comment:

To comment on Mr. Lamar's comment about credibility, there are many studies of life cycle cost which simply are not credible. Some of the problem exists because of lack of experience or lack of knowledge in the area. Some, perhaps were due to a zealousness to sell a component improvement or whatever. The credibility problem is a very real problem. In the government, if you are forced to make a decision with data that is not credible, you tend to discard it. Another need is that of improving standardization of terms. When your numbers differ from someone elses, is somebody hiding something? Not necessarily! The same words are being said, but with different meanings. Standardization is sorely needed in this area so that when one talks about life cycle costs or acquisition costs, everybody has the same understanding as to what the terms mean. There is a tendency to define terms to put a particular item or a particular point in the best interest at the moment. This is something that can be worked on.

Participant Comment:

One perception is that the concept of initially designing for both procurement and O&S costs is somewhat counter productive. Parts of Lewis' charts (3) indicated that the investment costs for aircraft flyaway with initial spares, plus the cost of replenishment spares, constitutes nearly 50% of the life cycle cost of many Army rotary-wing programs. Conceptually, if you can get the support people involved early enough, they can ensure, with a little work, that the concept of easy to repair in the field can flow into the concept of easy to build initially. Then you don't build something which is unrepairable in the field. Historically, R&D costs have been the easiest to estimate, because you can always use a fudge factor. The investment costs tend to be a little more obscure, but at least within grasp. The operating and support costs tend to be the grayest area. If you can get more of the emphasis on those pieces of the production costs which carry into the O&S, you can start achieving more credibility to the approach you are taking.

Round Table Comment:

Efforts have been made in many areas to obtain a better understanding of the production factors that relate to O&S costs. Reliability of course, is a very clear one to bring up. Analyses show, of course, that improved reliability increases acquisition cost, but projected O&S costs are reduced. A plot of total acquisition plus O&S cost versus mean time between failure (MTBF) will show a bucket, i.e. a minimum total cost at some value of MTBF. This is often the way the design MTBF is selected, or justified. One concern is that subsystem reliability trades are made without considering all system aspects. They may miss the fact that what really counts is the cost of the component installed in an aircraft, which may have to be maintained at various places throughout the world. You then have the cost of bringing the parts to the right place, and removing the old and installing the new part, and often an accessibility problem to get to the component within the aircraft. Many of us have heard about the case of the F-4 with the radio under the ejection seat. Everytime the radio had to be fixed up you had to take the seat out. That made the total radio maintenance very expensive. It also made the seat look bad. Such factors are being published in a series of booklets on "Logistic Lessons Learned" that will help the designer avoid problems of that type. Further, much more consideration is being given during the design phase to the identification of the driving cost parameters. Ones that are identified, including those relating to O&S, are being given considerable attention by most program offices. There is still the question, of course, of spending money today for potential improvements tomorrow. Even component reliability projections are often not valid. We all know that many such projections, which when compared with the actual performance in the field, may be off by a factor as much as 10 to 1. We even heard some higher ratios in this symposium. We need an improvement in that state of the art, especially when projections are important to have before test data is available, and even there, we often have poor results. New improved techniques which will more closely approximate operational environments should help.

Participant Comment:

In Germany, many things are being done in this area. A new regulation for development and procurement of new weapon systems was placed into use about 10 years ago. Next, we felt that much had to be done in the early preliminary design, or preliminary analysis

phases. We believe that all important decisions on new weapon systems up to now have been made, and in the future, will continue to be made during this early stage. This fact has required the military people to more carefully specify their operational requirements. Much work was needed in operational mission analysis, which of course has to be projected into the future. This requires an assumption that the technology of the future weapon system is feasible for stated amounts of money. Now, another facet of the problem: The reason for producing a weapon system is not to save a specific amount of money, or a specific percent of the cost of some other aircraft. The real job is to produce a defense capability, and we have this to do with a fixed budget. The question then is how to split up the budget, first into research to define technology and perform missions analysis during the early stage, then into development and support. We understand this now in Germany, and years ago we started what we call 'Future Technology Programs' with the industry and our research laboratories. The objective is to produce information on technology for future use, but it could be done more extensively. The process is understood but there are still problems.

Participant Comment:

Following the logic that's been developed that the government really cares, but does not fully know what to do, the question seems to lie in two areas. One is this inability to determine how much should be spent now for gains later. The other one is the difficulty that Mr. Lamar pointed out in adequately projecting future reliability vs cost. This is one area where the government does not seem to care enough to be sufficiently improving the data base that might enable us to make better projections. Early in the symposium it was pointed out that the records kept on maintenance do not require any assessment of why the failure, in hopes of keeping the work simple so that people will fill out the records. There should be a high payoff in getting more information on the reasons why, as well as the histories, for the maintenance and failures in the field. Analysis of such data would enable people to make better fixes and improve future designs.

Round Table Comment:

This is a very important point. The engineers among us have enough background information to decide how much life we can get from a wing, or how much strength we can get from a strand of carbon fiber, but when we come to life cycle costs, our data base is thin. This problem affects both sides of the argument, and it emphasizes that we need to do something positive to improve life cycle cost. We need more data to work with, or we can traipse around all over the place and get nowhere.

Participant Comment:

The Ministry of Defense is a very large organization, and is organized in essentially three service areas. Each area, has its own responsibility for procurement to meet the needs of its service customer. Each will attack a particular problem in its own way, so there is no single answer on policy, at the moment. In the area of Air Weapons and Electronics, the government is very concerned about costs. Further, cost concern is so great throughout the government, it appears that there will be reductions in government service. This may have the effect of reducing some of the documentation previously referred to! On the other hand, the pressures on costs will force industry to assume more responsibilities. This is the way the Air Weapons and Electronics area is proceeding at the moment. In the past, designers have seen their responsibility to keep costs down in designing their equipment. They have looked at the best production methods and talked to the service customer to some extent, but this has varied much depending on the designers ability and initiative rather than because of a general policy. The step we need to take next is to establish some ground rules and guidance papers for industry to follow in a more formal method, so that we are assured that the right practices are being adopted, and it's not left to individuals to operate in an ad-hoc fashion. Advisory papers are now being generated with the help of such organizations as the Cranfield Institute of Technology on design for economic production and advice to designers. In due course, this will hopefully become a mechanized form of advice, so that a designer will have computerized call-up of the data, and check lists of the important considerations needed to design for economic production. Guidelines will require consultation with the service customer in a formal way, rather than an ad-hoc way. Overall, the advice that has been given by many speakers in this conference will be written into the procedures for the designer.

Participant Comment:

The Air Force has a program to computerize a manufacturing costs design guide, essentially as a part of the CADAM system of computerated design. The designer will draw a part on the CRT, push a button, and the system will give the planning and associated cost for that particular part. This will give the designer more visibility into cost. It may not be exactly a standard for any one particular company, but it will be a standard that will permit comparisons between two different parts, for example having one of them going through a heat treat cycle vs another type of approach. Thus, government in the U.S., at least through the Air Force, is attempting to work with industry to try to be more concerned with costs.

Round Table Comment:

Clearly every guideline we can get for reducing costs, be they advisory documents, or computer programs, are helpful and certainly will be welcome. The designer welcomes

more information on costs. In many cases it has been denied him in the past, although all good designers try to design for reduced cost. One worry - if we find ourselves with guidelines and computer programs that then become part of the specification, we come back to the specification designing the airplane before the designers even had a chance to start.

Participant Comment:

There are differences between Government and Industry. The government has a problem in that funding is year by year. Further, it's not for a function within the design, but only for a phase of the work. Consequently, people are reluctant to spend their money for the benefit of someone else in future years. They are much more concerned about their own money and spending it in the optimum way this coming year. This basic structure of government can be a great hindrance to forward planning, just simply because of the way that money is collected and spent. It's also true in industry. In a competitive situation in the U.S., it has been possible to include DTC or LCC conditions in the contract. It is unlikely that such conditions would be acceptable to aircraft companies in Europe, simply because competition is lacking. There may be a need for more incentives to a company to design to cost or design for life cycle costing.

Participant Comment:

The UK has a very competitive situation. Some 50% of our sales are to overseas customers, and in these markets, we are very much in a competitive situation. As such, we are very concerned with DTC and welcome the moves made by the UK MOD on this subject.

Participant Comment: One must remember that the first things a constructor wants to do is to sell his product. There is plenty of incentive for the constructor to bring his acquisition costs down so he sells the product. Does the government take sufficient interest in life cycle costs? The answer is yes, but its not quite sure that collectively they know what they want. There is a danger if the product office defines in great detail, quite exotic life cycle costs requirements. But the formative time, as has been so much emphasized in this meeting, is the critical time. However, there is a great danger that if the constructor makes every effort to provide high reliability and low maintenance, he will produce a product that has a relatively high acquisition cost. The funding authority will suddenly say that is impossible, and instead may buy an obsolescent air vehicle that is off the shelf, that's half the price and only does half of what the original specification required as a technical requirement. There's a great need to specify the funding available at the very early stage. This clearly is beginning to happen in the U.S., but it's not clear in Europe.

Round Table Comment

The chair hasn't given the other Round Table members a chance to say anything. Discussion has been left to the floor as planned, but now let's open it to them too.

Round Table Comment:

In relation to the overall design to cost philosophy, it's great to establish a cost consciousness amongst all concerned, and that's what this program is doing pretty well. Over the last 25 years, operations and support cost, including manpower, has doubled as a percent of budget. That has caused a significant decrease in the quantity of new aircraft that we can buy. Both government and industry share this problem, in that we don't recognize a front-end, non-competitive environment where we try to determine what the major items are in a design to cost philosophy. We need to get funds transferred to O&S objectives which may involve more than a single system acquisition, and may involve technology applied against broad categories of equipment. The increased percentage of budget for O&S arises from all the systems that are being operated and supported. The answer to this is not clear, and its questionable if we collectively know what to do in the front end to attack this problem. Addition of more money on this problem is not likely, unless we move it laterally. It's going to be a percent of the budget for some time. Nevertheless, we should make small inroads into system O&S cost by improvements to reliability and maintainability. I use the word 'small', because in most of the technology that I've seen so far, a 40% improvement in design will not much change the actual propulsion shop in the field. Therein lies the problem.

Participant Comment:

Firstly, an awful lot of data is floating around, but we must fully accept the need for more, but perhaps better, data. Perhaps we ought to be looking at our data gathering system to see if the data being asked for is really useful. Many of the computer printouts and other paper produced now for our current projects are hardly ever looked at, and the data they provide is not of much use. Employment in the paper industry might pay a lot more than working on aeroplanes! Secondly, there is a tendency of reporting for the sake of reporting. Let us make sure the reporting is necessary. One of the remarks inferred we could be involved in more reporting. We do an awful lot of reporting already, but lets not get anymore that's not necessary.

Participant Comment:

In relation to previous remarks that we should lay down some rules and guidelines for contractors to follow, it certainly doesn't mean that they are going to generate a lot

more paper and the need for reporting. If the principals are accepted, and all manufacturers will be fully involved in debating the principals and a paper on which this procedure will be based, it will be of mutual benefit. We shall also improve the administrative agreements. This does not necessarily mean more paperwork, but it may mean there will be computerated devices for the designer without the need for paper. He'll have a visual display unit to quickly get his data.

Round Table Comment:

Asking the designer to join in the formulation of these papers or guidelines is a good move. We will want a continuing dialog. This is the most important thing perhaps, a dialog between the services, or the manufacturer and the government, and so forth. As an example of efforts for improved maintainability, we have always had onsite a service maintenance team which lives very close to the design office, and has access to the drawings and mockups. They've been able to come back to us in the early stages of a new design and say "I could never get a spanner on that nut the way you've placed it. Do something about it". That's a relatively effective way of getting cost effective maintainability, because you catch something before its gone too far, and you have the advantage of advisors who have been closely working with the product in the field. This is one of the more effective ways of improving maintainability and reducing life cycle costs. It is something tangible, something we can get our hands on, and it is using communication to the best possible effect. Perhaps there are other examples of how you can get a cost effective improvement.

Participant Comment:

We are talking about the second and third order effects. We've already established that the first order is the specification and the requirement, and here we are worrying whether a wrench fits a nut or whether there's a cost effective way of replacing a switch. Is there any indication that the government, the military, really do recognize that the first order term in cost is in the specification and the requirement?

Round Table Comment:

Of course, If the government doesn't know that specifications can be expensive, it doesn't listen because the contractors tell them that all the time through the AIA and the other principles! Actually people in the government fully understand, and much effort is aimed at simplifying and reducing specifications. The YF-16, for example, was procured on the basis of a specification that as I recall was some 10 pages long. However, the production system specification is another matter. You must recognize of course, that on the one hand, we say let's reduce the specifications, and on the other hand, let's have warranties, and other incentives. These incentives have to be measured against achieving certain goals, which have to be clearly spelled out on a piece of paper, and that means a specification. And so we go round and round on this. There is a plan for major improvements, but again like many things, it's shy of the manpower to do the job very quickly. Existing specifications are being reduced in number and combined to provide a set of specifications that are flexible in application and provide useful guides. Each will have an accompanying document on how to use the specification. It describes the basis for each specific provision of the specification and whether it is based on hard data, or just the best data available. This plan is along the lines of Mil Spec 8785B which has used that technique for sometime. There is also what is sometimes termed a 'murder board' review of all specifications and other contractual provisions for new system or major subsystem procurements. This effort also reduces the number of specifications. Maximizing government use of available contractor paper, and minimizing need of additional reports for the government has much merit. Experience in a major program which used that technique, with full access to contractor data showed it to be most effective, since you could quickly use the latest data that was available, it wasn't delayed and specially rewritten for the government. It was the real data that the engineers needed to understand and accomplish the program, and you could get to it very quickly. It eliminated the need for the contractor to prepare a lot of additional data and additional reports. With some restrictions, this technique has been used for other programs to reduce the need of additional reports. So there is a concerted move to reduce the amount of specifications and data. However, there is still a lot of paper. Part of it stems from the need for clear understanding of the system and procurement, the responsibilities of both contractor and the government, the laws that relate to procurement, and checks to preclude someone stepping out of line.

Participant Comment:

My comment here goes s step beyond the specification. We do not always understand how the government approaches the set of requirements that an aircraft has to meet in order to be the answer to a given threat. Trades between weapons capability and aircraft capability, between aircraft performance and low signal of the airplane, e.g. lower IR and lower radar reflection, and so forth. Those are the highest level items which produce the costs. An example of the same thing occurs if a private person goes to an architect and asks him to quote the cost of building a skyscraper or a bungalow. If you really want the skyscraper, then you fix the cost regardless of how simple you make the specification for the skyscraper. If you ask for the bungalow, then all the value engineering, everything we've talked about, means just refining the type of building in detail, putting walls in the right place and making it nice. The real mountain of costs, and the overwhelming input is the result of the government's requirement. A critical point then is how one determines the current or future threat. Do we foresee it right, as it will develop?

Do we simply extrapolate the threat, rather than modeling something new, rather than taking into account step functions that might occur on the other side, as well as in our countries. Once the threat is properly described, we must consider more than only one alternative, not simply consider the performance of fighters in the 50's, 60's and 70's, and then draw an envelope around all of the capabilities of aircraft developed for air-to-air, and build a new aircraft that can perform all the single best points, the best L/D's, the best C_L max, the best of everything at one time. That is the point we had to discuss.

Round Table Comment:

There is full, 100% agreement on that point. That is an extremely high payoff area. When you outline the basic nature of the system, that's where you determine what the costs are going to be, be it the aircraft system equivalent to either a skyscraper or a bungalow. There is a lot of work underway in the U.S. to improve the requirement determination process. OMB circular A-109, previously noted, (4) required that there be continuing mission analyses and tradeoffs between the kinds of factors mentioned. Now there's always an issue whether or not those are done properly, but there is an effort to improve the process, but more effort is needed.

Round Table Comment:

Two points have not been adequately stressed. One, we should wonder why design to cost, which is really a methodology, is not more strictly applied within industries. Design to cost means a tailoring of the organization, breaking down the work, defining objectives, using methods like Value Engineering which generate creativity. We don't sufficiently stress this particular aspect. Two, the definition of sound design objectives. Perhaps in the military these are more difficult to define than in the civilian field. In the civilian field, we have better knowledge of competition than in the military world. This is a point which should be thought about.

Participant Comment:

Two facts have generally been agreed to by all the speakers this week. One, the conceptual or early design phase commits about 78% of the total program cost, and two, the largest proportion of program cost is roughly equally divided between the production and operating costs. Now there are three points not yet addressed by any of the speakers. One, during the early definition phase, what are the dangers in applying credibility factors to submissions from the various competing suppliers in order to choose the right ones since you're going to be committed to them for a very sizeable program. The U.S. programs explained to us seem to go through a distinct prototype, early production, or pre-series program, into full production program. Unfortunately, our firm does not have that facility. We are now productionizing the aircraft on the standard of the third prototype, which has not yet flown. So design to cost, life cycle cost type activity does not take place in this type of environment, or are there dangers there? None of the speakers has discussed the modification programs that have taken place on their aircraft, and the effect on the life cycle cost.

Participant Comment:

Certain aspects of design to cost and life cycle cost, particularly in the field of military aircraft need discussion. First, let us describe a totally hypothetical situation for those here who belong to the military world. Let's imagine that we're members of an alliance, where, one, we're fully informed of the present, current and future capacities of the enemy, and also know the interests of his government. Two, NATO countries absolutely have decided to prevent any future conflict, and if not possible, to win it. Three, NATO nations have also decided to use all possible resources to obtain those objectives, while limiting them to what is strictly necessary, and finally, four, necessary funds, qualified manpower, and other resources are available. Those principles stated the ideal prerequisites for implementation of DTC and LCC philosophies without any restrictions. Are these conditions fulfilled in the case of NATO? Very far from it. Unfortunately therefore, we are compelled to have reservations on certain aspects of these underlined principles. It's essential to develop and use new methodologies and techniques in order to decrease costs for a given level of performance, or capability, for very general sorts of missions. Industries on both sides of the Atlantic apply this principle, but for a given performance. Conversly, trade-offs between performance and costs are extremely risky in the field of military aircraft, and should be used with extreme moderation and caution. Just the determination of required performance has considerably increased the responsibility of military planners, the right to error being zero. It would be very interesting to have comments from those here from the military world.

Round Table Comment:

Unfortunately, we are thin on the military side here. I think what has been said so far, is that we are floating around from design to cost on the one side and life cycle cost on the other, all part of the total cost of ownership. The point made a little earlier on the importance of the specification is one of much concern. The F-16's reduced size specification of some 5 - 10 pages is a tremendous improvement over the average specification that I see these days, although in the time period 1948 some extremely good airplanes came out from 4 pages of specifications. One can wonder if even slimming down to the order of 10 is sufficient these days. Over specification, both as regards the details of Mil specs, implies that the governments often essentially designs the aircraft

before the manufacturer has a chance to work on it. Good manufacturer's are generally capable of designing an airplane to meet a given requirement, and it doesn't have to be detailed. Will specs improve aircraft? Many aircraft today are not as good as they should be for service use because they have been over-specified by too much detail in specifications, specific equipment, or specific tests that they have to meet. Perhaps this occurs because everyone wants a hand in the act, or someone wants an airplane that is everything to all men, is a good fighter, is a good bomber, and everything at the same time. Can we do something to improve this situation? (Everybody's stunned to silence)

Round Table Comment:

Just to clarify a detail. The reduced size specification was for the YF-16. It was basically a performance type spec and not how to design the aircraft. However, when the production F-16 was started, the specifications became more extensive.

Participant Comment:

The comments there about specs, big specs vs. short specs etc. maybe hit a key point. Looking at the U.S. history with one of our wide body military transports, it's interesting to note that at one point in time the largest digital computer program that the contractor had was to optimize their payoff on the fixed price incentive contract. It had nothing to do with flight dynamics, structures, or other technical areas. So that's a pitfall. Now another interesting point, until a few years ago, all of the incentives had been paid off, but all the penalties were in litigation in court. So maybe we've left two critical groups out of this meeting, the procurement people and the lawyers,and that might be our biggest factor as far as specs go.

Participant Comment:

The YF-17 and YF-16 prototype competition phase specs were limited to only two or three page long, performance specs. Once the F-16 went into the FSD phase, they went back to the full blown specification requirements that the Air Force needed.

Round Table Comment:

That's likely increased the cost considerably.

Participant Comment:

To follow up on the funding problem, once the weapon system has been selected, in the U.S., politics exert a considerable effect, and causes changes in funding levels and schedules. This has an adverse affect on the total program cost, and a lot of other activities. Money is now being spent to improve spare support for current systems in order to maintain some force level. Previously, when hostilities seemed more remote, funds for spare parts and buy of new airplanes were reduced. Now we're seeing the adverse affect. There should be some rethinking in terms of funding. Once a program is selected, some stability should be maintained in production and the transition into the operational side. Without that, we're going to continue to see this movement up and down, and arguments of how we reduce cost and get money to buy airplanes That's part of the problem. The other one is to get the politicians out of the procurement cycle.

Round Table Comment:

There should be another factor interposed over the ones that previously were stated, and that's called fear of failure which goes along with, not the specifications, short 10 page specifications are great, but the problem is if you don't follow with 10 pagees of justification and proof, you're in trouble.

Round Table Comment:

There is a song "Everything you can do, I can do better" that relates to the problem. We should think more about the comment made about the importance of requirements, and also the implications of competition. In the interactions between the government on one side, and industry on the other side, we have one kind of competition. It is good to have prototype stage competition, although its not clear how we can mechanize this in Europe. But if you don't have competition, you may pay for it very much. The other point is we have a different kind of competition between the Warsaw pact nations and the NATO countries. Governments overreact to the activities on the other side and sometimes cause costly perturbations to system requirements and programs. For example, TV publicity of rather 'antique' types of helicopters, with no counter-measures, flown by the Russians in Afghanistan resulted in statements that our anti-tank helicopters should be expanded into additional air missions. It is costly to overreact and impose additional requirements on aircraft already existing in the design stage. As long as the governments do not soften this kind of overreaction, the industry of course has to respond, but at eventual cost to the taxpayer. This is also an important aspect of life cycle cost or design to cost.

Round Table Comment:

We have talked about many aspects of my first question. Do governments really care from both the government and the industry sides, and back again. Clearly, we all have a problem. Airplanes tend to be expensive whichever way you play it. We've heard some ponters as to how costs might be reduced, but there is still a long way to go in achieving

results. We haven't addressed the other 3 questions yet, at least not directly. Now to turn to question No. 4, "Can the Military Learn any Lessons from the Civil Side?". Mr. Carlson will speak first.

Mr. Carlson:

Going back to a few of the comments from the floor, it is worth noting that we have as much working paper on the commercial side as the military side, e.g., we pass just as much paper internally within the company on a commercial airplane as we do on a military one. The difference lies in the control mechanism. In the commercial area, the paper goes across the board to help reach decisions made 'eyeball to eyeball'. This term is used because when you talk across a table, with the necessary data available, you can talk about the question, the answer and come to a decision solution in a matter of a short time. That's the way it operates. Now the reason it operates very well, is that we know from the start, before we put the lines of the new airplane on paper, what our market price is roughly. We also know how much of an advantage we have to have over McDonnell-Douglas, for example, so we start out with a market price. The objective is to then design the best airplane we can get within the time frame to that market price. We tend to shy away from allocated targets. We like to see top level goals. We like to leave our manager underneath with the maximum flexibility to move his money and people laterally to work a problem where he has cost growth, or where necessary, to work a cushion in to cover the growth. In that way, we achieve improvement in the aircraft. That is freedom to design within the top level goal. Later on, after the airplane has been bought, we add more specific control mechanisms. We do have a few major low level reliability improvement warranties at times to make sure that we can hit that established goal and sub-target.

Within the DOD environment right now, A-109 talks about this in terms of a functional need. Not conceptually designing to a particular system, but designing to a functional need. What is the role of the designer, the system engineer, the strategy man who's working threat? What are all of them going to do together to lay down the considerations and requirements for this new system, whatever it is. There are many challenges with this in the military area. It is not easy to document. We're working with the government, and trying to help establish some procedures at the front end. Those are obviously not very clear, because the mission element need statements are not coming out very fast. When they do come out, they omit many of the operational and logistics type considerations. To put this into perspective, there's a distinct difference between designing to the marketplace vs. designing for military control, or speculating on inflation, or programming to fluctuations. They're separate and distinct, but some of them have to be tied together at the front end. Since we have run lessons learned studies on commercial vs military, we should use most of those major findings and rigorously enforce those in the front end of military aircraft, and look at it from the standpoint of the marketplace. To do that, we would need to better establish the equivalent of the marketplace in the military area. Several recent comments reverted back to threat, and how the scenario is written. The military analysts are doing a great job in putting some of the operational capability statements together, but when we put the whole thing together, which includes costs, logistics considerations, and a means of keeping the marketplace going over a span of time, then we have somewhat of a problem.

Participant Comment:

The military can learn a lot from commercial experience, and it starts right at the procuring agency. We are motivated in industry, both commercial and military, by profits. In the military market we have a problem, because if we want to spend production money to save O&S costs on a new fighter, for instance, the primary-benefit of that accrues to the next future fighter. There will be more money to procure the next fighter within a fixed defense budget, and the realities of procurement are that we're unlikely to be selected to build the next one. So right away you have a problem. If one goes to management and tries to convince them to spend some production or development money to save O&S costs, the risks to our management is that there'll be an overrun and we'll be rewarded by having our production buy cut. The solution is not clear, but that's one reason why we have so many specs. The government responds by issuing very specific requirements with specific demonstrations to make sure they get what they want. Then they include incentives to motivate the contractor artificially to achieve those objectives, since there's no direct profit in the way of a new program coming back to him. Perhaps the procuring agencies can devise a system to reward the contractor in the next competition for having done an excellent job in improving reliability and maintainability of his product. We haven't seen that yet.

Round Table Comment:

To comment on that, there is a greater trend, which may now be a requirement, to consider past performance in new source selection activities. It is a definite factor in source selection.

Round Table Comment:

Time now requires that we conclude the Round Table session. Can we draw any firm conclusions from our discussion? One thing clearly, both design to cost and life cycle cost need action early in the program. We all seem to be agreed on that. There appears to be agreement in saying don't over specify, for that will cost you more money. Clearly we all need more good data in digestible form to enable us to tackle the cost side of

things. Guidelines could be of much help here. Obviously, as in nearly all problems, we need more and better communication between the user, the manufacturer, and particularly the government who has some influence over the contractual and legal questions, as well as others. Surely, the customer can also do things to help himself.

III - CONCLUSIONS

This meeting addressed a number of important aspects of Life Cycle Cost (LCC), a subject of immense importance to the NATO nations. It was timely to do so. Costs must be minimized for the required military capability, with an adequate margin for undertainties.

Life Cycle Cost is a problem of many dimensions. No one meeting can address all aspects in any depth, and the Symposium covered a wide spectrum of LCC subjects, ranging from the importance of system requirements to cost analysis and innovative solutions to reduce the cost of detailed parts. It dealt in some detail with the key subject of DTC & DTLCC, covering perspectives, data bases, cost prediction methods, LCC principles, methodogies, approaches, analyses, organizational aspects, training, application of results, payoffs, and so forth. LCC aspects were considered from the system hardware perspective, considering key subsystems and components. LCC was also considered for each of the phases of a system life cycle. Considerable attention was given to the O&S phase, in part because of its high importance (50% to 60% of total system cost), and in part because of the need for substantial action to improve the understanding of this area. Review of the meeting result, in relation to the detailed objectives noted in the theme for the meeting shows that the planners well ensured that the objectives would be covered by the papers. A discussion after each paper and during the Round Table session was very active and involved a large percent of the participants. Some participants believed more attention was warranted on major impact areas, such as the impact of military requirements on cost, as will be noted later. All in all, the symposium was well balanced in the coverage of the many facets of LCC.

This assessment includes discussion of several topics which received much attention at the meeting in an effort to provide a useful perspective on the subject. These topics include:

1. LCC Perspectives
2. LCC as a discipline
3. Value and Viability of the DTC & DTLCC concepts
4. Cost Drivers
5. Specifications and Interfaces
6. Military Requirements
7. Specific Conclusions from Papers, Round Table and Discussion

1. LCC Perspectives

The basic problem is to properly balance required mission capabilities, timing and budget limits with a feasible and sufficiently robust system solution. LCC involves the analysis, prediction, control and reduction of costs for all aspects of aerospace and related technologies, manufacturing, testing, operation and supporting functions. Life Cycle Costs should not be considered in isolation from the overriding military need of providing an effective force capability. LCC of the overall weapon system force is a very complex problem not only in the scope of different functions and disciplines involved, but also in the depth or degree of the specific items that need be analyzed. Care must be maintained to assure that major first order effects are given adequate attention, even though much easier, small cost reductions can be achieved by examining the less important higher order effects. System costs are about equally divided between acquisition and O&S, although the ratio in some cases is 40 to 60. The O&S area is of special concern because of a lack of understanding and its high cost. Logistics research is needed to resolve the problem. LCC analyses can be costly to conduct and care should be taken to limit such analyses to areas that experience shows the likelihood of positive results. Serious gaps still exist in the data base necessary for credible LCC tradeoff analyses and decisions, especially in the O&S area. At the same time, many reports and data printouts which have little value for these purposes appears to exist.

The LCC process logically requires a breakdown of the system and its functions to the level needed to identify the major system cost drivers, and then further breakdown to identify the specific high cost components, elements or functions which can be meaningfully addressed to reduce cost. Reliance on normal engineering disciplines and experiences to then reduce cost may often be effective, but a number of examples showed a specialized team approach to be best.

Early investment in LCC cost reduction is critical in order to yield meaningful savings, but must be approached in a coordinated manner to achieve maximum effectiveness. Life Cycle Cost analyses are of key importance as an aid to establishing, reducing and controlling cost, but also have many other important applications:

a. A criterion in strategic decision making, design tradeoffs and in selections among options.

b. Improve understanding of basic design parameters during system design/development.

c. Determine cost drivers

d. Provide goals for program control.

e. Select best acquisition strategy.

f. As a criterion in source selections

g. Establish contractor incentives

h. Predict future budget requirements.

i. Assess application of new technology.

j. Optimize training requirements.

The utilization of a small interdisciplinary team of highly capable, innovative, design, manufacturing and cost engineers to analyze the requirements and initial design solutions, establish significantly reduced cost targets, and seek innovative solutions has shown high payoffs. This process in the European papers is often termed "value analysis" and "value engineering". Application of this term for an innovative group seeking large improvements early in the design process differs from the more traditional use of the term in the U.S.A.

2. LCC as a Discipline

LCC is a discipline to assure a systematic and logical process applied to cost reductions, cost control, and cost avoidance. It requires an understanding of its basic principles, and the establishment of approaches, methodologies, organization teams, and controls to achieve desired results. The symposium showed that a broad awareness of the need for cost reduction and LCC exists throughout NATO, although the maturity of understanding and implementation of the process varies. Cost is an integral factor in the engineering profession, and engineers have long sought the most efficient solution to a problem. Unfortunately, the complexity and magnitude of the problem can not be solved, even though it can be aided by the ad-hoc efforts and capabilities of individual engineers. A parallel might be that anyone, by diligent study and effort, can acquire an equivalent college education without going to college. Some in fact have, but the discipline of going to college is essential for most. Likewise the discipline and team approaches of LCC are necessary to achieve consistent results in cost savings, cost control and cost avoidance.

3. Value and Viability of DTC and DTLCC Concepts

The points and perspectives voiced by participants provides many perspectives to this key issue regarding the status, problems, progress and payoffs associated with the application of LCC concepts. Few, if any, indicated that the concept was fallacious; quite the other way. Concerns were expressed about several implications of the process as it is now viewed by some, e.g. excessive paperwork and additional restrictive specifications. Although these are not inherent to the LCC concept, some control procedures established to assure its implementation may require additional technical and accounting reports.

LCC does involve additional work. Any new capabilities or improvements require additional work. The issue is whether the gain justifies the expenditure. The process shown by Eslinger (22) which quantified the savings or 'gain' in relation to the cost reduction process is an interesting technique to measure the value added by the DTC/LCC concept, as well as showing impressive payoffs. Gableman, (23) noted several processes in the reliability area which measure the payoff of reliability improvement efforts versus the cost of achieving the improvements. Such measurement /assessment techniques deserve some emphasis. One may question the accuracy of the numbers, and the assumptions made in the assessments, but the evidence is clear from many papers. DTC and LCC concepts are yielding impressive gains in specific technical solutions and in cost reduction and control.

4. Cost Drivers

Cost drivers, like interfaces, exist at all levels of the system WBS. At the top, National policy and other such factors determine what type and mix of systems we need. At the system level, the military requirement is the prime cost driver, although there are others of major magnitude, such as political and economic perturbations and system development strategy, with cost impacts in the billions. At the other end of the scale, at WBS 6 or so, the coil tube assembly of the solenoid valve used in an engine fuel control system is a cost driver, as reported in one paper (27) which discussed the manhour analysis conducted to reduce the valve cost. Similarily, the cost driver in installing a detailed part might be the inability to place a 'spanner' on a nut because of inadequate clearance. There are several points to be made from this discussion. (1) Cost reduction is important at all levels. (2) The detail savings are trivial from a systems viewpoint, but there are many, many of them, they are amenable to a solution at little cost, and can add up to significant dollar savings over the life cycle of the system. A very small percent savings of a 10 billion dollar system is significant; a savings of only one hundreth of one percent is one million dollars, a very significant number. (3) Many small savings that can actually be achieved, with a sizeable net gain over the cost of the effort, are obviously far more productive than spending many resources to solve a major problem that doesn't yield a solution. (4) Nevertheless, the system level cost drivers can be moderated, and are of such major impact, that they demand a concerted effort to reduce cost. Cost should be worked at all levels.

5. Specifications and Interfaces

Much discussion evolved the desirability of simplifying and reducing the number of

specifications, some would like to see the number zero. Unnecessary specifications should be eliminated, but all are not in this category. In addition to performance specs, other types are essential to proper functioning. For example, interface/interaction requirements are frequently the basis for a specification. These are necessary when one element of a system must function in some ways with other elements of the system, or set of systems. Requirements for interfaces pervade all levels of the work breakdown structure of a system and require clear specifications to insure that compatability will be provided for adequate functioning of the item. If any elements are provided by the government or other sources, the interface must be specified, and this includes all relevant physical, mechanical, hydraulic, environmental compatability, functional, timing, repair concept, operational concept and so forth. Many requirements of this type exist between systems, such as an aircraft and the missiles it carries. Neglect of these needs could result in substantial cost increase.

6. Military Requirements

One issue that surfaced during the symposium related to the critical importance of military requirements to LCC, and concern that the symposia was spending time discussing very detailed items rather than addressing the key problem. During a discussion of the problem of providing clearance to place a spanner on a nut, one participant aptly noted that 'we have already established that the first order terms is the specification and requirement; why are we worrying about whether a wrench fits a nut?' Another participant added that 'it is the requirement that causes the cost', and gave the clear parallel of ordering a skyscraper vs. a bungalow noted in Section 5. The point was that once that decision is made, value engineering, cost reduction, etc. are little more than refinements compared to the overwhelming percentage of the cost caused by the requirement for a skyscraper vs. a bungalow. The similarity to systems if obvious. While a number of papers during the meeting discussed the criticality of the requirements, no paper was dedicated to this subject. The Symposium plan included LCC subjects that could be shared with others in a meaningful manner, whereas the requirements process is complex and would have required a classified meeting. The problem of specifying the military requirements of a system that will meet the threat with adequate margin at minimum LCC and with compatability with the total force structure is a very complex one involving many disciplines. It is also a problem that involves security and other sensitivities which tend to preclude full discussion. Without question, a discussion of LCC implications and interactions with military requirements would be a worthy topic for a future AGARD symposium. A discussion of the military requirement process itself which, involves analysis of the threat, mission and operational analysis, consideration of emerging technologies and system capabilities, and many other factors and interrelated activities of considerable complexity warrants a symposium, or session during one on system design.

7. Specific Conclusions from Papers, Round Table and Discussion

Numerous conclusions can be derived from review of the papers and active discussions of the meeting. Many would provide the basis or require another paragraph or section of this report, if all aspects were discussed. In the interest of conciseness, and since a detailed summary of the Round Table discussions, and brief summaries of selected aspects of the papers are included herein, and CP 289 is available, these conclusions will be summarized simply by brief sentences. For convenience, they are grouped in selected areas of interest, but it is to be noted that interaction with other groupings often exists. The writer has simply selected ones that from his perspective, seemed to fit the best. Conclusions of a similar type, but with a slightly different meaning or scope have been stated separately, rather than combined, in order to provide the reader a more complete perspective of the results. References to paper numbers or letter 'D' for discussion is included to show the source of the conclusion.

A. Life Cycle Cost Perspectives

1. The overall LCC problem is one of enormous complexity, however attention to all levels and elements can yield worthwhile cost savings. (4)

2. DTC & LCC are different. DTC addresses the cost of buying the system and involves money in the budget for the immediate future. LCC is concerned with the future. For systems now in service, the user may be able to reduce some costs, but the manufacturer can do little. For new systems, the manufacturer can improve total LCC, but he need incentives.

3. LCC is a method of forecasting the cost of future events, and is much like forecasting weather. (17)

4. The DTC phrase is often not fully understood in terms of its meaning and scope, and misuse of the concept as a design to financial feasibility can lead to over-simplification of the problems and serious deficiencies in the military capability. (19)

5. DTC means properly structuring the organization, breaking down the work, defining objectives, and using methods, such as value engineering which generate creativity.

6. It was generally agreed that (1) the conceptual or early design phase commits about 80% of the total program cost. (2) The total LCC is about equally divided between acquisition and O&S costs, but in the U.S. is closer to 40:60.

7. Costs are primarily caused by the military requirements, based upon military needs and tradeoffs between options. (D)

8. The reason for producing a weapon system is not to save a specific amount of money or a percentage of the cost of other systems, but to produce a defense capability. This is a factor LCC efforts must recognize. (D)

9. The idealistic design to LCC philosophy must be compromised, since tradeoffs between performance and costs are extremely risky in the field of military aircraft, and should be used with extreme moderation and caution. (D)

10. Overreaction to adversary activities, without full consideration, can unnecessarily perturbate requirements and increase costs. (D)

11. Cost is an active element of design, and an integral part of system engineering.(6)

12. Engineers have traditionally sought the best and lowest cost design and production, and to some extent work with the customer, but this has been on an ad-hoc basis, varied and dependent upon the individual designers ability and experience, rather than because of a general policy. A more formal method with specific rules and guidance papers is needed. (D)

13. Both industry and government share the cost problem. (D)

14. Continuous dialog between the government, services, or other users and the manufacturer in formulating guide lines is vital for reduced LCC. (D)

15. Political influences cause budget fluctuations, which in turn perturbate aircraft development and production schedules, thereby adversely affecting total program cost. (D)

16. The need of discounting current expenditures for future gains currently requires a gain of one dollar 10 years from now to justify spending thirty-nine cents now. (D)

17. People are reluctant to spend money to benefit someone else in future years. There is a need for more incentives to cause them to do so. (D)

18. Major improvements in design may not result in much change to the actual cost in the field because of the established organizations, manpower levels, and procedures. (D)

19. The credibility of LCC studies is a very real problem. Government tends to discard such studies. (D)

20. A real question is how to split up the budget, including design/mission analysis. (D)

21. Increased emphasis on LCC, fed by pressures on cost will force industry to assume more responsibility. (D)

22. System contractors are capable of designing an aircraft to meet a given requirement which is simply stated. Over-specification costs much and is not needed. (D)

23. A major challenge is to integrate the military requirement and operational capability statements, logistics considerations, and LCC, with a means of keeping the market place efficient over a span of time. (D)

24. Use of a prototype reduces follow-on system risk and technical uncertainties, and avoids cost increases. (9)

25. Institutionalization of LCC is now well established (4)

26. DTC goals will discourage demands for additional performance that increase cost. (3)

27. Cost is becoming more important than technology requirements during design and development. (3)

28. DTC has been effective in controlling production cost. (3)

B. Data Base

1. Much data is now available, but better and more specific data is needed. (D)

2. Many computer printouts and other data currently produced are of little use. A major effort is required to assure that only that actually required is generated. (D)

3. LCC data is expensive, only quality needed should be obtained. (1)

4. Lack of consistent definitions or understanding of the meaning of definitions leads to variances in the accumulation of cost data and misleading results in analysis. (D)

5. New VAMOSC system will provide major improvements in the O&S data base, with traceability to black box level. (2)

6. Credible reliability and maintenance cost data is very difficult to acquire. (23)

7. Different intepretations of parameters involved in maintenance significantly effect the accumulation of cost data and use for LCC analyses. (20)

8. Inadequate government attention appears directed towards improving the data base, e.g. maintenance records even with the newest system do not require any assessment of failure causes, even though this information could be invaluable in providing better fixes and improving future designs. (D)

C. Cost Drivers

1. System performance, mission capability, and O&S requirements are the key cost drivers. (D)

2. O&S cost drivers strongly affected by the design including unit spare cost, fuel, MTBF, MTTR, personnel skills and numbers, maintenance concepts, and utilization rates. (18)

3. Over-specification can result in an inferior product and considerable increased cost. (D)

4. The high cost of fuel, now over 50% of the DOC for DC-10 justified acquisition of fuel efficient aircraft. (14)

D. O & S

1. Over the past 25 years O&S costs, including manpower, have doubled as a percentage of budget. (D)

2. Research on the O&S process and logistics systems is critically needed. (5)

3. Lack of attention has increased O&S costs and reduced operational availability. (5)

4. An avionics methodology relates LCC and operational availability parameters in quantitative terms and provides for tradeoffs. (23)

5. Little matchup exists between design/maintenance concept used in development vs ownership deficiencies in the field. (5)

6. Use of people and material in a timely and more economical manner is a critical need. (5)

7. More emphasis in designing to personnel feasibility is required to reduce O&S cost. (19)

8. Increased involvement of support people early in the development cycle would permit meshing of the concepts of easy to build and easy to repair. (D)

9. DTC is only marginally effective in the O&S area. (3)

10. O&S cost can be controlled by coordinating approach to LCC during the design stage. (7)

11. Engine ownership cost are significantly larger and different from those indicated by past studies. (25)

12. Industry is motivated by profits and the opportunity for future business. Diverson of production funds to reduce O&S costs will increase its unit production cost and likely reduce sales. The result will be more money in the future to help fund the next fighter; which will not likely be given the same contractor. This reduces incentives to reduce O&S costs. (D)

13. Reliability centered maintenance (RCM) program which emphasizes on-condition maintenance, and the concept of maintenance as the means of protecting and restoring the inherent reliability of aircraft has produced considerable cost savings, and should be useful for other complex systems. (16)

14. Numerous lessons learned in reliability, maintenance and other O&S areas are important to understanding and improvements. (D)

15. Engine component improvement performance cost as much as the initial engine. (25)

16. Subsystem tests in a facility which simulates a realistic operational mission environment (OME) can substantially improve field reliability. (8)

17. High operational readiness is dependent upon systematic development of the O&S characteristics during the system engineering process. (24)

25. Reliability incentives are included in both system and subcontracts for the F-16 and F-18. (8-9)

26. Selection of mean time between failure values to determine reliability objectives should consider total system aspects and not just subsystems. (D)

27. Reliability projections are inadequate. Comparison of predictions often differ from actual experiences in the operational environment by a factor of 10.(D)

28. Effort by a contractor to provide high reliability and low maintenance cost will increase the acquisition cost of his product, thereby jeopardizing his sales. This reduces incentive to improve R&M,unless counter-balanced by others.(D)

29. Improvements to reliability and maintainability are important but will make only small inroads into reducing O&S costs because of the 'built-in' costs of the O&S process. (D)

30. Demonstration of the achievement of maintainability targets involved a number of issues and is not straight-forward. (20)

31. Improved system maintenance features may not be realized in the field because of insitutionalized organizations and processes. (5)

E. LCC Analyses and Methodologies

1. LCC analyses are of major importance to the attainment of a balanced performance, schedule, minimum cost solution to design and development of weapon systems. (18)

2. LCC is of ever increasing importance as a tool for strategic decisions, detailed tradeoff studies, design optimization, establishment of management policies and sales. (1)

3. A strong committment to LCCA will provide payoffs and is critical in the long term. (7)

4. Cost analysis should be viewed as the continuous interface between the desirable and the feasible. (6)

5. Cost analysis is an essential tool of system engineering in determining impact on cost of requirements and constraints for evaluation of alternatives. (6)

6. Cost predictions are of key importance in cost effectiveness tradeoffs. (11)

7. LCC analyses are essential in quantifying the factors and parameters in tradeoff studies. (18)

8. Credible technical and cost information for a genuine DTC program requires increased depth of system definition and cost analysis during the design phase. (21)

9. Lack of LCC estimating credibility is a major problem in applying results. (7)

10. Cost estimates vary widely between contractors. (7)

11. Cost predictions suffer innacuracies when new technology is involved. (11)

12. A method for measuring and incorporating the effect of technology changes has been applied in the avionics area. (23)

13. The highly knowledgeable analyst can compensate for many of the data base problems. (2)

14. Aircraft system contractors through their integration responsibility must take the lead in effective cost reduction efforts for the entire system and develop basic concepts for application of DTC. (11)

15. Systems engineering techniques and a preliminary design/mission analysis process provides a powerful tool for the exploration and tradeoff of system alternatives. (4)

16. LCC provides an important figure of merit or design criterion for decisions among alternatives. (18)

17. Sufficiently accurate relative total cost estimates yields high payoff as a criterion for decisive system decisions, and a basis for warranties and equipment contracts. (21)

18. LCC analyses provide valuable inputs for source selection decisions, resource planning, and trade study selections. (18)

19. A LCC model capable of accurate assessments at the component level is essential for evaluating the LCC payoff of advanced engine component technologies

and other subsystems. (26)

20. Models have been devised for avionic subsystems which permit assessment of the cost of reliability improvement efforts in relation to the reliability improvement attained. (23)

21. Decisions about engineering performance/schedule cost must be made at the system level and not based on the engines alone. (25).

22. Continued evolution of selected LCC models throughout the program will aid program control, and permit improvements to the model. (D)

F. Contracts

1. Working paper requirements for commercial aircraft development are about the same as those for military aircraft, but the use is different. In the commercial area data is used to quickly reach decisions in "eyeball to eyeball" meetings, thereby avoiding costly delays. (D)

2. Efforts underway in the U.S. to simplify, reduce and consolidate specifications, and provide supplemental users handbooks should improve the process and help reduce costs. (D)

3. A formal critical review of specifications and other contract provisions by an interdisciplinary 'board' before contract definitization can simplify requirements and reduce cost. (D)

4. Increased government use of the actual paperwork required by the contractor to accomplish his job can reduce the need for additional reporting and reduce cost. (4)

5. Numerous contractor incentives are contained in the contracts of the F-16 and F-17. (8-9)

6. Award fees are effective in motivating contractors to perform tradeoff studies and to meet reliability and maintainability targets. (9)

7. Use of incentives can result in excessive attention by the contractor to maximize his award fees rather than producing the best engineering solution. (D)

8. Credibility factor adjustments to contractor proposals would improve source selection. (D)

G. Advanced Technology

1. Aircraft contractors must take the lead in applying innovative technology solutions to systems and assist other contractors in assisting the system impact of their subsystem and component technologies. (1)

2. The system design mission analysis process offer an excellent means of evaluating new technologies. (4)

3. Application of advanced technology offers significant system cost savings. e.g. 11% gross weight, 6% cost and 4% fuel for an advanced combat aircraft. (11)

4. Assesments of the LCC impact of advanced engine technology should consider the total weapon system LCC. (26)

5. Advanced technology components such as complete structures must be evaluated in terms of the total system LCC not just that of the component. (11)

6. New technology can reduce system cost. More emphasis on cost reducing technologies is needed. (4)

7. Advanced cost reducing engineering technologies can provide significant reductions to both engine and system LCC. (26)

8. Integrated structural design provides an effective method of reducing structural component and system cost with attendent significant weight reductions. (10)

9. Cost and time of systems with advanced design concepts and technologies can be reduced by more extensive use of technology demonstrators. (4)

H. Key Factors and Payoffs

1. Innovative new technologies, available low cost materials, and equipments and numerous tradeoffs and cost minimization principles are the key to success. (9)

2. Keys to success are realistic requirements, serious trade studies, rigorous design reviews and multi-discipline design terms and incentives. (8)

3. Top level cost goals have advantages in permitting lower level managers the

maximum flexibility to solve problems and accomplish their jobs. (D)

4. Key to success is timely and credible analysis plus mature judgments. (1)

5. Cost trades early in the program are of key importance, since some 80% of LCC is comitted by the time 8% of funds are expended. (1)

6. Cost reductions up to 30% can be achieved by use of multi-disciplined management techniques during the initial design phase. (25).

7. F-16 and F-18 experiences show major payoffs attainable by use of LCC concepts. (8-9)

8. Training of personnel in value analysis and DTC methods, and the establishment of interdisciplinary teams for specific tasks provide high payoffs in achieving objectives. (12)

9. Cost reduction DTC/DTLCC activity on landing gears, wheels and brakes show a major cost reduction through application of a concept involving industrialization, value analysis, and design to life cycle cost. (22)

10. Key to substantial reductions in hydro-mechanical aircraft parts was competent, and trained personnel working in teams, rapid and reliable calculation methods, and continuous cost control. (22)

11. Use of DTC concepts with extensive innovative design by a small, highly competent team provided major simplifications to design, extensively reduced numbers of parts, and reduced fabrication costs for the SA 350 to 12.6% of the total production cost, compared to 47% for the SA 318. (15)

12. Major cost savings in the SA 350 program were achieved through major simplifications to design and extensive reduction in the numbers of its parts. (15)

13. DTC experience utilizing a disciplined process and innovative value engineering has shown reduction in the cost of hydro-mechanical fuel controls of some 20% for new parts and 8-10% for existing parts. (27)

14. DTLCC of aircraft brakes reduced cost per landing by 70% and initial production cost by 45%. (22)

15. The key to reduced structural cost and weight was a simple design rule - keep the number of parts and fasteners at a minimum. (10)

16. The payoff of a value analysis/engineering activity to reduce cost can be assessed by a factor R equal to the ratio of the cost savings during a two year period divided by the cost of the studies. Typical values of R have been between 14 and 22. (22)

17. Overly formal LCC system not needed. (1)

18. Design to LCC is little different than designing to other technical parameters. (8)

IV. RECOMMENDATIONS

1. A strong committment to LCC is essential, and should be maintained by government and all contractors.

2. System plans and budgets must recognize that the purpose of the system is to provide a needed military capability, and that neither the threat estimates on which requirements are based, nor the LCC tradeoffs on which costs are based, are precise. The margin for error in needed military capability is slim, and errors could be very costly.

3. Active dialogue between government, specific users, and industry should be maintained on a continuous basis, instituted in areas now lacking, and increased in areas of key importance, with a sufficiently structured process to involve all relevant levels, and provide for consolidation of findings and feedback of results.

4. Greater use should be made of technology demonstrators as a strategy in system development, and means of exploiting technology advances, in order to reduce time delays and costs with the long step process to system development, but reduce risks, and avoid the high cost of solving problems associated with fully concurrent programs.

5. NATO/AGARD action should be taken to standardize or equate differences in terminology that currently result in ambiguous communication and intepretation of data, obscure important differences, and degrade the credibility of data aggregations used for data base analysis and LCC actions.

6. Data bases should be reassessed to eliminate current serious gaps, and eliminate costly unnecessary costly data.

7. A dedicated and well coordinated research and analysis effort should be conducted on a continuous basis to adequately understand, define, and model the complete O&S process for both peace and potential hostilities. It should resolve data base and analysis needs, determine the cost impact of the system mix, personnel skill and manpower levels, and other important factors in order to assure identification of all cost drivers and devise means of reducing the LCC of the total system force.

8. Maintenance data systems should include data on the specific causes of failures, and be supplemented as needed by correlated data from more detailed failure mechanism and cause analysis where the specific failure mechanism can not be determined in the field.

9. Assessments and decisions regarding systems and subsystems tradeoffs should be made on the basis of impact on systems LCC. Credible LCC estimates should be developed and used as a "figure of merit" or key criterion for these needs. Summaries of gaps in the data base that are critical to achieving this result should be provided the government for appropriate action.

10. Increased costs during the design phase may be necessary for adequate LCC tradeoffs, innovative team actions to reduce cost, and for definition of the system and program in sufficient depth to permit credible cost estimates for decision purposes. This should be recognized as a key need in reducing total acquisition and LCC, and be provided in program budgets.

11. An integrated mission analysis and LCC analysis process should, with an assessment of uncertainties, be utilized throughout the program to guard against over-reducing or over-specializing design operational and support capabilities, in order to reduce budgets or costs during tradeoffs, when such actions could well lead to inferior military performance relative to the threat, inadequate operational availability, and increased O&S costs.

12. The selected LCC models should continue to be evolved throughout the program for use in tradeoffs and program control, and to permit improvements to the model as experience and data is acquired.

13. LCC modeling efforts to accomodate and assess the effect of new technology should be given continued support.

14. A concentrated inter-disciplinary team effort, employing innovative design and technologies to reduce costs and establish minimum, but realistic cost targets, should be a key effort during the initial phase of each program.

15. An effective training program should be utilized to assure a significant segment of managers, engineers and cost analysts, from engineering, production, tests and program control are fully aware and knowledgable regarding the basic concepts and methods of LCC cost.

16. Increased emphasis should be applied to the development and application of cost reducing technologies.

17. Continued emphasis should be applied by government in simplifying and reducing requirements, specifications and contractural constraints, and in seeking means of assuring acquisition of a fully satisfactory product by a less costly means.

18. A dedicated funding allocation to analyze and implement specific O&S cost reductions should be included in the budget for all systems and subsystems, with a requirement for adequate LCC analysis, justification of expenditures to replace that already allocated to O&S considerations, and feed back to measure and assess results. The U.S. PRAM experience well demonstrated this value. (4)

19. Adequate contractural provisions should assure that specialized incentives do not overly absorb contractor attention and compromise achievement of the total required system capabilities.

20. Cost of military systems is of critical importance. This symposium should be but the beginning of periodic symposia on the subject. Needs range over the spectrum, and include detailed reviews of the state of the art, activities, underway, problems, progress, results, and case studies of system and subsystem applications of the LCC data bases; cost analysis and prediction methodologies; LCC aspects of conceptual/preliminary design; LCC methods (Principles, organization staffing, procedures, problems, payoff); the O&S arena including logistics research and as previously noted, LCC aspects of the system requirements establishment process.

APPENDIX 1

List of Papers

SESSION IV - LCC OF SUBSYSTEMS AND COMPONENTS (cont'd)

25. "Application of DTC and LCC to Aero-Engines (AGARD LS 107)"
E. J. Jones, MoD, UK

26. "The Role of Advanced Technology on Turbine Engine LCC"
R. F. Panella, USAF Wright Aeronautical Labs., USA

27. "Cost Considerations of Engine Fuel Control Systems"
A.J. Eccleston, Lucas, UK

APPENDIX II

Acronyms

DTC - Design to Cost
DTLCC - Design to Life Cycle Cost
FSD - Full Scale Development
LCC - Life Cycle Cost or Life Cycle Costing
LCCA - Life Cycle Cost Analysis
MOD - Ministry of Defense, UK
MTBF - Meantime Between Failure
MTTR - Meantime to Repair
O&S - Operations & Support
OMB - Office of Management & Budget, USA
OME - Operational Mission Environment
R&M - Reliability and Maintainability
RCM - Reliability Centered Maintenance
RIW - Reliability Improvement Warranty
WBS - Work Breakdown Structure

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